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Effects on daily mortality of droughts in Galicia (NW Spain) from 1983 to 2013

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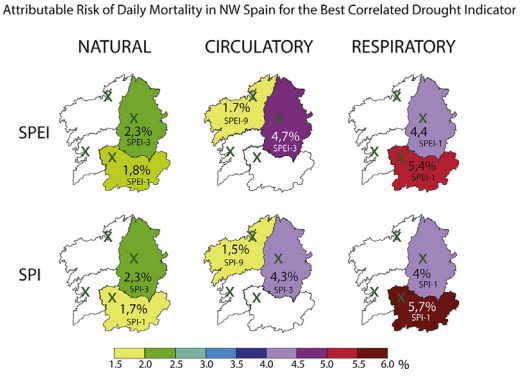
HIGHLIGHTS

- Drought periods had a greater influence on mortality in the interior provinces.
- Mortality was mainly manifested for longer timescales of SPEI/SPI in the Coastal.
- In short-term, the effect of droughts and heatwaves was observed in interior zones.
- In short-term, the drought effect on mortality was mainly explained by pollution.
- There are hardly differences between SPEI and SPI for the mortality risk estimation.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change scenarios indicate an increase in the intensity and frequency of droughts in several regions of the world in the 21st century, especially in Southern Europe, highlighting the threat to global health. For the first time, a time-series diagnostic study has been conducted regarding the impact of droughts in Galicia, a region in north-western Spain, on daily natural-cause mortality, daily circulatory-cause mortality, and daily respiratory-cause mortality, from 1983 to 2013. We analysed the drought periods over the area of interest using the daily Standardized Evapotranspiration-Precipitation Index (SPEI) and the daily Standardized Precipitation Index (SPI), obtained at various timescales (1, 3, 6, 9 months), to identify and classify the intensity of drought and non-drought periods. Generalized linear models with the Poisson regression link were used to calculate the Relative Risks (RRs) of different causes of mortality, and the percentage of Attributable Risk Mortality (%AR) was calculated based on RRs data. According to our findings, there were statistically significant ($p < 0.05$) associations between drought periods, measured by both the daily SPEI and SPI, and daily mortality in all provinces of Galicia (except Pontevedra) for different timescales. Furthermore, drought periods had a greater influence on daily mortality in the interior provinces of Galicia than in the coastal regions, with Lugo being the most affected. In short term, the effect of droughts (along with heatwaves) on daily mortality was observed in interior regions and was mainly explained by atmospheric pollution effect throughout 2000 to 2009 period in Ourense, being respiratory causes of mortality the group most strongly associated. The fact that droughts are likely to become increasingly frequent and intense in the context of climate change and the lack of studies that have considered the impact of droughts on specific causes of mortality make this type of analysis necessary.

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1. Introduction

1.1. Droughts and the risk to public health

Several studies have demonstrated the vulnerability and exposure of many human systems to the current climate variability, highlighted by the recent impact of climate related to extreme phenomena, such as heatwaves, droughts, floods, cyclones, and forest fires (e.g., McMichael and Lindgren, 2011; Handmer et al., 2012; Watts et al., 2017).

Furthermore, climate change scenarios indicate that hydrological extremes, like droughts or floods, will be more frequent and intense in the 21st century in several regions of the world (e.g., Stewart et al., 2015; Sapionini et al., 2017; Wang et al., 2018; WHO, 2018; Zhaoli et al., 2018), with important effects in Europe (e.g., Guerreiro et al., 2018). Specifically, in Southern Europe, a 15% decrease in precipitation and a large increase in temperature (e.g., Vicente-Serrano et al., 2011) have been predicted. Although there have been several studies regarding the effects of floods, there are much fewer on the effects of droughts despite their dangerous global impact, due to the complexity in assigning the beginning and end of the events and their accumulated effects over time. In addition, many of the effects of droughts are indirect (Vins et al., 2015; Ebi and Bowen, 2016; Berman et al., 2017). Every year droughts affect several million people and the most recent data available from the international disasters database (EMDAT) estimate that >50 million people around the world were affected by droughts in 2011 (Stanke et al., 2013). In addition, between 1960 and 2013, about 600 drought events resulted in 2.19 million deaths and 2.14 billion affected people (Sena et al., 2014). Moreover, the Lancet commission in 2015 indicated that a change in population from Shared Socioeconomic Pathway 2 (SSP2) and climate change could lead to 1.4 billion additional people exposed to drought events per year by the end of this century (Watts et al., 2015), what could be associate with greater morbidity and mortality (IPCC, 2014; Yusa et al., 2015; Berman et al., 2017). One of the most notable effects of drought is the decrease in air quality. Droughts often have secondary effects, such as dust storms and forest fires, leading to an increase in the concentration of fine particles (PM), dust, and smoke, and they are also associated with alteration of dispersion of allergens. All these events could lead to increased risk of respiratory tract and/or cardiovascular diseases, and could result in mortality (Sena et al., 2014; Yusa et al., 2015; Stanke et al., 2013; Berman et al., 2017; Watts et al., 2017; Bell et al., 2018).

Among the few studies on the effects of droughts on health is a recent study from the USA, which showed that in more severe drought conditions the risk of mortality increased in adults over 65 years, with the particularity that, those regions that had previously suffered fewer drought events had a higher risk of cardiovascular disease and mortality (Berman et al., 2017). This fact reflects the great importance in emphasizing the effects of droughts, which are projected to occur with greater intensity and duration in future climates, on global health. Although a decrease in respiratory hospital admissions during periods of drought is described in Berman´ study, Smith et al. (2014) showed for the Brazilian Amazon that drought events led to increased hospitalization for respiratory diseases of children under five years old.

On the other hand, droughts also have a long-term influence on the modification and degradation of the environment and ecosystems. Droughts are a growing threat to the increase the risk of malnutrition, infectious diseases, problems associated with mental health and human well-being disorders, and to changes in the ecology of vector borne diseases (e.g., Berry et al., 2010; Shukla, 2013; OBrien et al., 2014; Sena et al., 2014; Yusa et al., 2015; Vins et al., 2015; Bell et al., 2018; Berman et al., 2017).

All these effects will interact with the susceptibility and vulnerability of the reference population, socio-economic factors, adequate access to health infrastructure, and underlying demographics factors, whose combined influence can aggravate some of the existing threats, creating new challenges in health care (Stanke et al., 2013; IPCC, 2014; Ebi and Bowen, 2016).

1.2. The metric of droughts and the estimation of health effects: the crucial role of drought indicators

The impact on health largely depends on the severity of droughts (Stanke et al., 2013; Ebi and Bowen, 2016; Berman et al., 2017) and, in this sense, drought indices are essential measures for quantifying and identifying possible changes in the frequency and duration of the risks they measure. Drought indicators make it possible to obtain better knowledge and undergo preparation to tackle the drought effects on health (Vicente-Serrano et al., 2017). One difficulty in studying the different effects of droughts lies in their own definition, as they are classified into four categories: meteorological, hydrological, agricultural, and socioeconomic (Bachmair et al., 2016; Ortega-Gómez et al., 2018). In addition, droughts differ from other environmental phenomena in that they are a slow developing hazard (Bachmair et al., 2016). There are continually an increasing number of indicators, but there is no specific index designed to measure the type of drought in reference to its impact on health, so each index can differ in its estimation, and each type of drought can affect health outcomes in a different way (Berman et al., 2017).

1.3. The study region: Northwest of the Iberian Peninsula (Galicia)

The Iberian Peninsula is considered one of the southern European regions that is most likely to suffer an increase in drought severity during the 21st century (Vicente-Serrano et al., 2011). This study focuses on Galicia, in the northwest of the Iberian Peninsula (Fig. 1). Galicia is an ideal region for studying the relationships between droughts and health, including analysing the meteorological and biological mechanisms, because its climate is very unique and varied (Gómez-Gesteira et al., 2011). It is surrounded by the Atlantic Ocean with its coastal areas marked by a mild and rainy maritime climate and an inner area that has a much less rainy continental climate, very warm in summer and cold in winter. In terms of precipitation mechanisms, Galicia is located in the southernmost part of the Atlantic storm track (Dong et al., 2013), and its extremes of precipitation are strongly influenced by the occurrence of atmospheric rivers (Gimeno et al., 2014; Eiras-Barca et al., 2018). Furthermore, its climatic variability is closely linked to several and important teleconnection patterns as the North Atlantic Oscillation (Lorenzo et al., 2008). Concerning to weather conditions, a particular study in Galicia showed an increase in respiratory admissions associated with cold, dry weather, or anticyclonic types (Royé et al., 2016). In terms of the environmental mechanisms that link droughts and health, Galicia has one of the highest incidences of forest fires of all the regions in Europe (Fuentes-Santos et al., 2013). Galicia certainly is the region in Spain where more fires have occurred and more hectares have been burned. In 2017, there were 3249 forest fires and 62,000 ha that were burned (Mapama, 2017). In addition, Galicia has two coastal industrial poles, one in the North (A Coruña) and the other in the South (Vigo in Pontevedra) with strong emissions (García-Santiago et al., 2017), and has undergone intense heatwaves with potential effects on health (e.g. Decastro et al., 2011).

In this study, we report the first evidence of a relationship between drought exposure and the daily risk of specific causes of mortality in northwest Spain. With the exception of the Berman et al. (2017) study, few works have evaluated the effects of droughts on specific daily causes of mortality, so, analysis such as the work presented here in this paper are necessary to gain better understanding in adopting strategies of management and preparation as well as create early responses to reduce the negative health effects attributable to hydrological extremes.

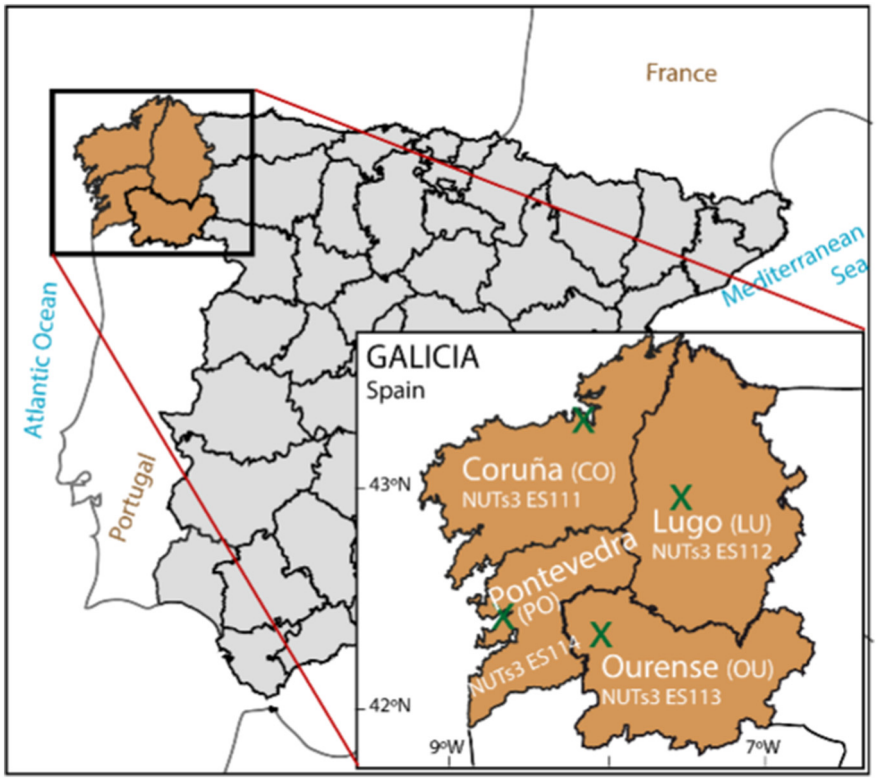

Fig. 1. Region under study. Our focus is on the Galicia region, situated in northwest Spain, during the period from 1983 to 2013. The subdivision (provinces) corresponds to the European NUTs3 administrative regions: Coruña (ES111), Lugo (ES112), Ourense (ES113), and Pontevedra (ES114). Green crosses denote the position of the capital of each province: A Coruña (43.36° N, −8.41° W), Lugo (43.01° N, −7.56° W), Ourense (42.34° N, −7.86° W), and Pontevedra (42.43° N, −8.65° W).

The main objective of this study is the evaluation of the impact of drought, measured by the Standardized Evapotranspiration-Precipitation Index (SPEI) and the Standardized Precipitation Index (SPI), on daily natural, circulatory and respiratory causes of mortality in Galicia, Spain, from 1983 to 2013. For its approach, we conducted the following aims:

I) Evaluation of the effect of this hydrological extreme on different causes of daily mortality using SPI and SPEI obtained for different timescales (1, 3, 6, and 9 months), throughout 1983 to 2013 period.
II) Integrated analysis to control the effect of heatwaves and pollution levels along with drought periods measured by short-term to determinate the effect of these strongly associated climatic variables on the different causes of mortality from 2000 to 2009.

2. Material and methods

We conducted a retrospective ecological study of daily time series to evaluate the impact of droughts on daily mortality from different causes in Galicia, at NW Spain, during the period from 1983 to 2013. The variables involved in the study are outlined below.

2.1.1. Dependent variables

The dependent variables include the daily natural-cause mortality classified according to the International Code Disease 10 (ICD10: A00-R99), daily circulatory-cause mortality (ICD10:I00-I99), and daily respiratory-cause mortality (ICD10: J00-J99). These mortality data refer to the daily mortality for the capital and towns over 10,000 inhabitants in each province of Galicia from 1983 to 2013. The provinces correspond to the following European NUTs3 (Nomenclature of Territorial Units for statistics level 3) administrative regions (Fig. 1): A Coruña (ES111), Lugo (ES112), Ourense (ES113), and Pontevedra (ES114). All mortality data were provided by the National Institute of Statistics (INE) of Spain.

2.1.2. Independent variables

To quantify the drought conditions in the four provinces of Galicia, we used two meteorological drought indices: the SPI (Standardized Precipitation Index), which is based on precipitation data, and the SPEI (Standardized Evapotranspiration-Precipitation Index), which incorporates precipitation and evapotranspiration data, to take into account the atmospheric evaporative demand. The SPEI and SPI time series were obtained from the Spanish Superior Council of Scientific Researches (CSIC) website: http://monitordesequia.csic.es (see Vicente-Serrano et al. (2017) for more details). The complete drought dataset is available with 1.1-km spatial resolution and a weekly time resolution (4 time-steps per month). Both indices could be obtained at various timescales (1, 3, 6, 9, 12, 36, and 48 months) that reflect the impact of drought on the availability of different water resources. The different timescales correspond to different accumulation periods, which are associated with different drought types, such as 1 month in length (short-term conditions) for meteorological droughts, 1–6 months (short- and medium-term conditions) for agricultural droughts, and 6–24 months or longer (medium- and long-term conditions) for hydrological drought. In this work, we select SPEI and SPI for the accumulated periods of 1, 3, 6, and 9 months to analyse the effects on health from meteorological, agricultural, and hydrological droughts. Hereafter, the length (n) of the accumulated index will be denoted following the index type as SPEI-n or SPI-n.

In our study, we selected weekly drought data from 1983 to 2013 over each capital city of Galician province (green crosses in Fig. 1) that they are the highly populated areas with high representation of the total population to construct the four time-series of SPEI-n and SPI-n for the same period as we have for the mortality data (ICD10: A00-R99, ICD10: I00-I99 and ICD10: J00-J99).

As the drought data are available weekly, we construct continuous daily series assuming the same conditions for each seven-day interval to obtain better control of acute daily confounding factors, following the criteria of Berman et al. (2017).

Commonly, the onset of a drought episode is defined when the index value falls below zero and the episode ends when the index returns a positive value; furthermore, its severity could be quantified applying some thresholds (based on a normal distribution). Following the criterion of Agnew (2000) and Berman et al. (2017), the drought conditions were ranged from 0 to 5, where 0 is 'no drought' and 5 is 'exceptional drought'. A drought period is classified as level 0, when index value is below 0 and higher than −0.84, and it is considered "usual" conditions or a "mild drought". Level 1, "moderate drought", corresponds to values between −0.84 and −1.27; this interval reflects a 20% probability that a similar drought could occur in 5 years. Levels 2 and 3, "severe drought", occur if values are between −1.28 to −1.64 (reflecting a return period of 10 years with a 10% probability) and between −1.65 to −2.05 (return period of 20 years with a 5% probability), respectively. Levels 4 and 5, "extreme drought", correspond to values between −2.06 to −2.33 (return period of 50 years with a 2% probability) and values less −2.33 (return period of 100 years with a 1% probability), respectively.

The continuous original SPI and SPEI series data were used to conduct the main statistical analyses, while the categorized series were used with a statistical purpose and to check the role of the severity when significant results were founded (see Table 2 in the supplementary appendix).

Fig. 2 shows SPEI-1 for Ourense from 2001 to 2013, as an example, of the continuity of the index (Fig. 2A) and the severity classification (Fig. 2B).

2.1.3. Analysis variables

We conducted two type of analysis in this study: Aim I) The analysis of the drought impact on natural, circulatory and respiratory causes of daily mortality from 1983 to 2003 period, and Aim II) The evaluation of the impact during 1-month drought accumulation (SPEI-1 and SPI-1) also being taken into account the combined effect with the heatwaves and pollution throughout a sub set of 10-years period from 2000 to 2009, when pollution data for A Coruña, Ourense and Pontevedra are available. We controlled these independent variables because they are strongly related with daily mortality at short-term.

2.1.3.1. Drought variables. We have used two daily SPI-n and SPEI-n indices with the goal to which of both is the better proxy for detecting the impact on daily mortality. As it was commented previously, SPEI is obtained mathematically in a similar way as SPI but it includes the temperature (Bachmair et al., 2016; Vicente-Serrano et al., 2010), facilitating the evaluation of any possible differences in the drought effects on daily mortality related to it.

As the objective of this study is to evaluate the impact of drought on daily mortality by the various described causes, the original continuous SPEI-n and SPIE-n values were retained in the analysis to measure the intensity of the event.

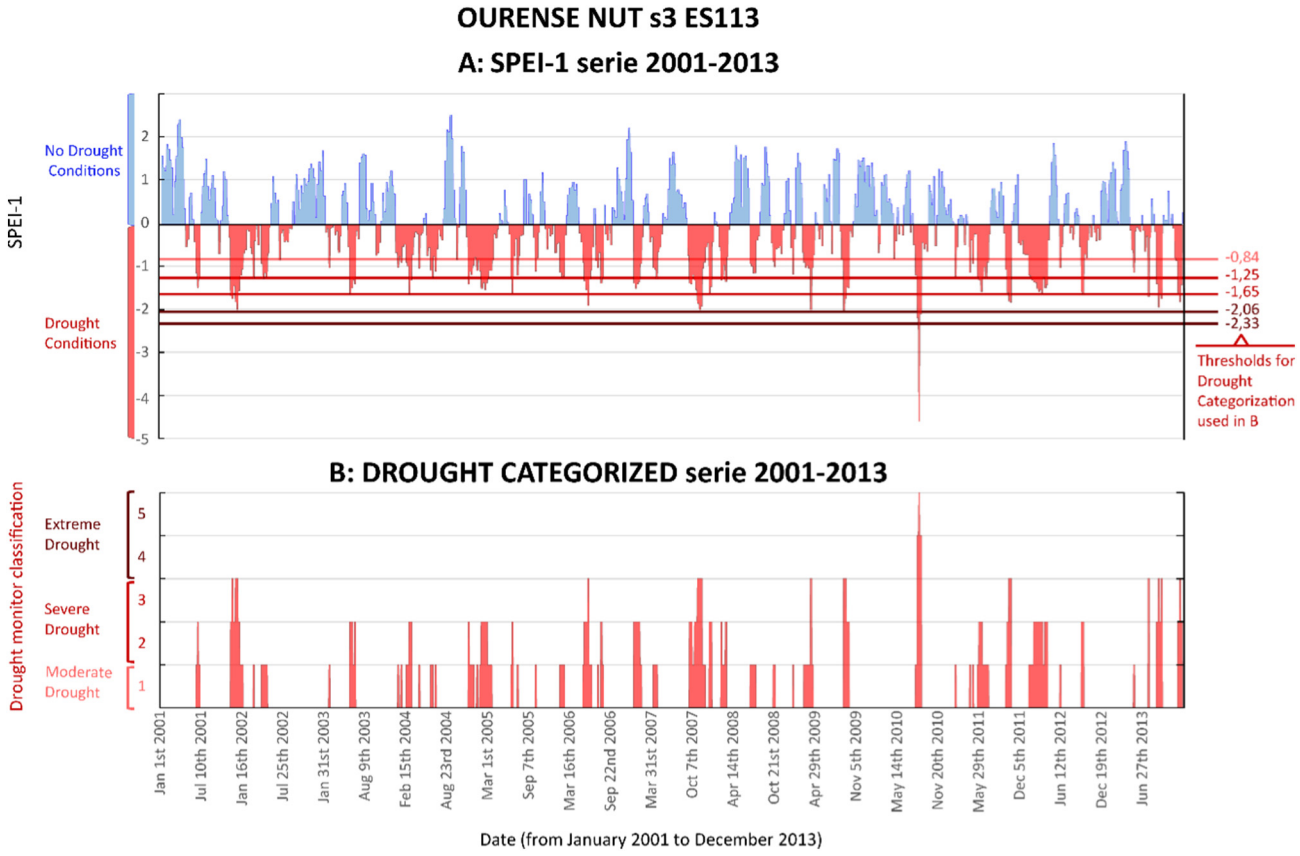

Fig. 2. Drought characterization measured by SPEI-1 for Ourense, Galicia, Spain (NUTs3 ES113) across 2001 to 2013. A) Time evolution of the SPEI-1 values. In blue days with no drought conditions, and in red the days with drought conditions. Horizontal continuous lines indicate the different thresholds that allow the classification in severity following Agnew (2000). B) Categorized drought measured by SPEI-1. Five different groups were distinguished gradually from 0 ("no drought") to 5 ("exceptional drought") as in Berman et al. (2017), and according to Agnew (2000) thresholds. SPEI-1 greater than −0.84 is considered "no drought conditions", and the SPEI-1 is set to 0. For SPEI-1 between −0.84 and −1.25, SPEI-1 is set to 1, considered as "moderate" drought conditions. For SPEI-1 between −1.25 and −1.65, SPEI-1 is categorized as 2; and for SPEI-1 between −1.65 and −2.06, SPEI-1 is set to 3. Both SPEI-1 = 2 and SPEI-1 = 3 are considered "severe" drought conditions. For SPEI-1 between −2.06 and −2.33, SPEI-1 is categorized as 4; and for SPEI-1 lower than −2.33, SPEI-1 is set to 5. Both SPEI-1 = 4 and SPEI-1 = 5 are considered "extreme" drought conditions.

In reference to the first aim, we used SPEI and SPI obtained at four different time scales (1, 3, 6, and 9 months) to evaluate the manifestation time for daily mortality due to drought. We used these time scales because they are the most common accumulation periods for meteorological indicators (Bachmair et al., 2016). In reference to the second aim, we only used droughts measured at short-term (SPEI-1 and SPI-1).

Other variables were controlled throughout the study, as in Sánchez Martinez et al. (2018): i) The trend of the series was introduced by taking n1 = 1 for day 01/01/1983, n1 = 2 for 02/01/1983, and so on to the end of the series (31/12/2013). ii) The autoregressive nature of the dependent variable was controlled from the autoregression of the first order of daily mortality. iii) We also categorized by seasonality of the series: annual (365-day), six-monthly (180-day), four-monthly (120-day), and quarterly (90-day), using the sine and cosine functions that correspond to these periodicities. In the second part of the study, to control the seasonality in summers, which are four months, we also controlled the seasonality of 60.

2.1.3.2. Heatwave and pollution variables. Additionally, we have controlled several independent variables to carry out the second aim of the study related with the heatwaves and pollution from 2000 to 2009.

To consider the effect of the *heatwaves* it was accounted the daily "temperature for heatwave" (T_{hwave}), as in Diaz et al. (2015), calculated as below:

$$T_{hwave} = Tmax - Tthreshold \quad if\ Tmax \geq Tthreshold$$

$$T_{hwave} = 0 \quad if\ Tmax < Tthreshold$$

where Tmax is the maximum temperature recorded at the reference observatories located in the provincial capital cities, and Threshold is the maximum temperature threshold for daily mortality attributable to heat calculated in Diaz et al. (2015). This threshold for A Coruña is 26 °C, for Lugo 34 °C, for Ourense 36 °C, and for Pontevedra 30 °C. Tmax data were supplied by the State Meteorological Agency (Agencia Estatal de Meteorología/AEMET). From a point of view of daily mortality impact, we have considered a heatwave day when Tmax surpasses the Tthreshold (Diaz et al., 2015).

We also use *pollution* as an independent variable. Specifically, we control daily mean O_3, PM_{10} and NO_2 concentrations (in $\mu g/m^3$) recorded at monitoring stations situated in each capital province. These data were furnished by the Ministry of Agriculture and Fisheries, Food and Environment (Ministerio de Agricultura y Pesca, Alimentación y Medio Ambiente, MAPAMA).

The effect of air pollution on mortality may not be immediate, and it can occur up to 5 days in case of PM_{10} and NO_2 (Ortiz et al., 2017; Diaz et al., 2018; Linares et al., 2018a) and up to 9 days in case of O_3 (Diaz et al., 2018). In the case of temperature, the effect on daily mortality can delayed up to 4 days (Diaz et al., 2015). For these reasons, only droughts in short-term were considered here, and in the statistical models we also controlled those known lags.

2.2. Process of analysis and models

In both parts of the study, the impact of drought conditions on daily mortality for each province of Galicia was quantified using generalized linear models (GLM) with the Poisson regression link. We used single models for independent SPI-n and SPEI-n series. This process was conducted individually for natural, circulatory, and respiratory causes of daily mortality.

Respect to the second part of this study, firstly, we evaluated the impact of drought combined with temperature on the different causes of daily mortality, and then we added pollution independent variable in the model.

Poisson modelling makes it possible to determine the relative risks (RRs) of mortality in respect of the variables which resulted statistically significant. Subsequently, RR of the variables in terms of drought was calculated from the value of the estimator obtained in each model ($e^{|coefficient|}$), calculated for each unit of increment for the indicator of the independent variable used (Royo-Bordonada and Damián-Moreno, 2009).

The p-value was determined using the step-back procedure, in which the complete model that included all the analysed explanatory variables was initially implemented, with those variables that individually showed less statistical significance gradually eliminated until concluding with a model that included just the statistically significant variables ($p < 0.05$).

The percentage of attributable mortality risk (%AR) for the population associated with a particular drought time was calculated based on RR, following the equation: $\%AR = [(RR-1)/RR] \times 100$ (Coste and Spira, 1991), representing the percentage of the increase in daily mortality effect associated with the drought in the population exposed to this risk factor.

All analyses were performed using the software IBM SPSS Statistics 22 and STATA v 14.1.

3. Results

3.1. Descriptive statistics of the episodes of drought in Galicia, NW Spain, and mortality causes

The descriptive environmental and mortality characteristics according to drought conditions in the provincial capital cities of Galicia, in the period 1983 to 2013, using SPEI and SPI metrics obtained for the time scales of 1, 3, 6 and 9 months were evaluated. The total number of daily deaths by different causes were tabulated, according to the categorization of days with drought for each provincial capital city of Galicia (see Table S1 in the supplementary material).

In terms of drought exposure, the percentage of total days with drought is between 18.36% and 28.17%, with the highest percentage in Lugo (24.19% to 28.17% using SPEI and 21.62% to 25.40% for SPI). In general, a higher percentage of total days with drought has been observed in the interior provincial capital cities of Galicia (Lugo and Ourense) than in the coastal ones (A Coruña and Pontevedra) for all timescales using either indicator, except for A Coruña in the long term where there was a greater number of days with total drought than in Ourense.

On the other hand, both indicators showed a higher percentage of total days with drought in all provinces for 9 months of accumulation: in A Coruña for SPEI-9 (SPI-9) there were 25.96% (22.93%) of days with drought, 28.17% (25.40%) in Lugo, 25.36% (21.01%) in Ourense, and 22.47% (19.58%) in Pontevedra.

There were differences between the number of drought days when the severity was taken into account between different regions and in terms of the drought timescale. In Lugo, for instance (where the maximum total days with drought were counted) for SPEI-9 it was obtained 47.02% of days with moderate drought, 51.57% with severe drought, and 1.4% with extreme drought. For SPI-9, the percentages were 44.25% days as moderate drought, 52.85% as severe, and 2.89% as extreme. However, SPI for shorter periods (SPI-1 and SPI-3) showed fewer days with drought than SPEI-9 and SPI-9 but more days with extreme severity, with 13.64% for SPI-1 in Lugo and 14.51% for SPI-3.

Finally, adding drought days categorized as severe and extreme, in general terms Lugo reached the highest values, while Pontevedra had the lowest.

3.2. The impact of droughts on the different causes of daily mortality

A complete statistical analysis using the Poisson GLMs was done trying to find the statistically significant relationship between the continuous daily SPEI-n and SPI-n drought indicators and daily mortality by different causes in each provincial capital city of Galicia, from 1983 to 2013. From the estimator values obtained from the Poisson models,

the Relative Risk value (RR) for each cause of daily mortality related with extreme hydrological events was calculated.

3.2.1. Daily mortality causes under drought conditions during 1983–2013

Fig. 3 shows a graphic summary of the estimated relative risk (RR) of the different causes of daily mortality associated with droughts measured by both indices when a statistically significant relationship exists at a confidence level of 95% ($p < 0.05$). Table S2 included in the supplementary material describes the complete statistically significant p-values as well as the complete values of the RR, estimators and those of the 95% confidence intervals of estimators and RRs. The RR values are described in the following section.

The general results of this study (see Table S2) indicate a high variability for each province. Roughly, droughts had a greater influence on daily mortality in the interior areas (Lugo and Ourense) than in coastal ones (A Coruña and Pontevedra). According to these, in Lugo drought conditions, measured by both SPI and SPEI, were associated with a statistically significant increase in daily natural-cause mortality as well as an association with both specific circulatory and respiratory causes of daily mortality. In Ourense, an association between droughts periods measured by both indices and daily natural and respiratory causes of mortality was statistically significant, but there was not a direct relation with daily circulatory-cause mortality. However, in A Coruña there was only an association with daily circulatory-cause mortality attributable to drought conditions measured by both SPI and SPEI, while in Pontevedra there was not a statistically significant relationship between any of study variables.

3.2.1.1. Period in which the effects of droughts were manifested on natural, circulatory and respiratory cause mortality for SPEI n and SPI n at different months. The study also revealed that the statistically significant manifestation of the effects of the drought conditions periods (for all months of accumulation) in any daily cause of mortality was very similar SPEI or SPI for the four provinces (Fig. 3, Table S2) during 1983 to 2013.

Although the findings in daily mortality attributable to droughts measured by SPEI-n and SPI-n were equivalent, we can see subtle differences in Fig. 3 between both indicators in terms of the estimation of relative risk. In particular, the figure shows that in Ourense the association of daily natural-cause mortality with drought conditions was statistically significant only for the short term (1 month of accumulation) by both indices; while in Lugo the effect was also observed for the medium term (3 and 6 months) and long term (9 months). In the case of A Coruña and Pontevedra, no statistical significance was found between daily natural-cause mortality and either drought index. With respect to daily circulatory-cause mortality, in Ourense no statistically significant association was observed with droughts. On the contrary, in Lugo

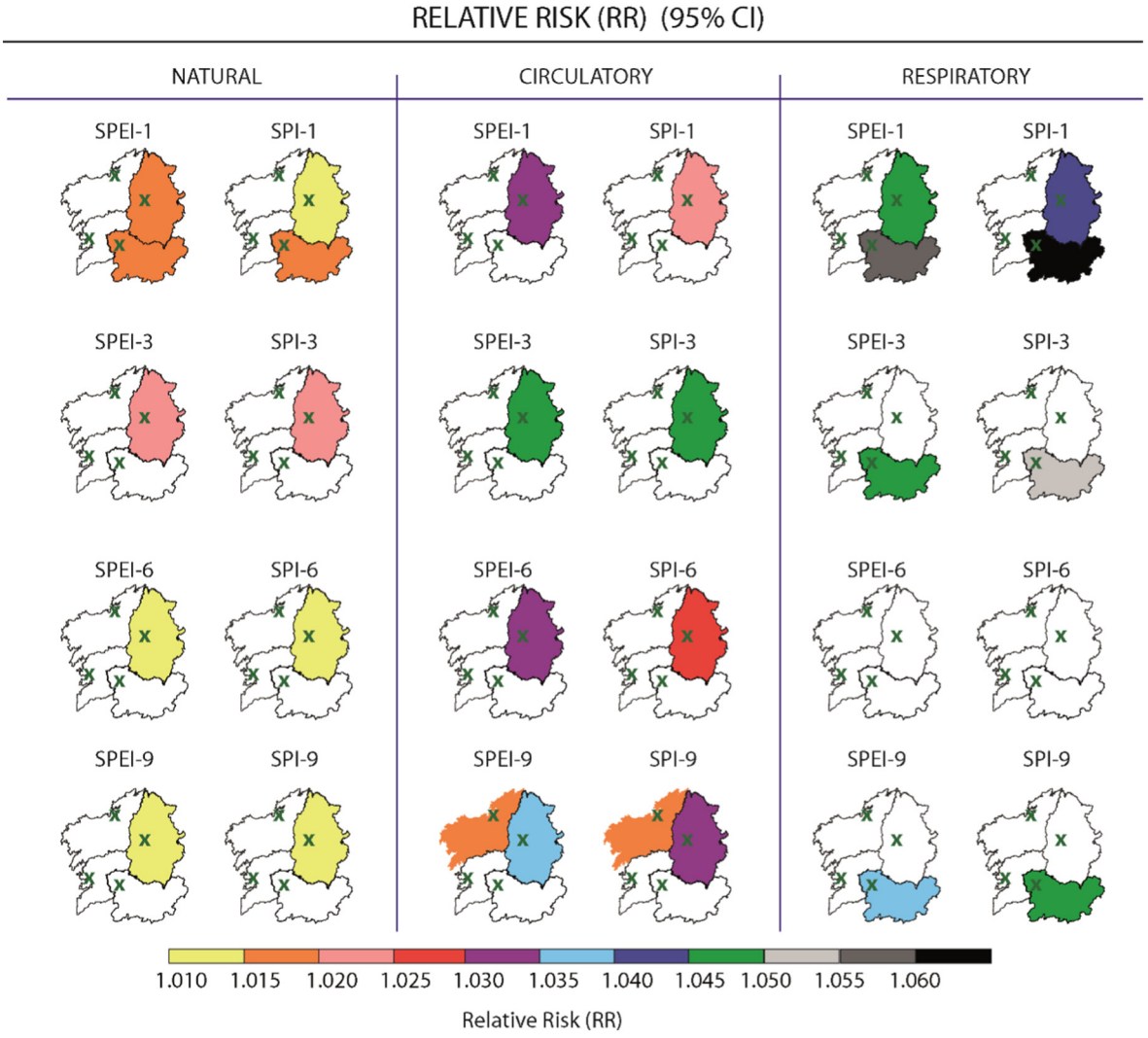

Fig. 3. Summary of representation of relative risk (RR) of natural, circulatory, and respiratory causes of daily mortality attributable to drought periods in northwest Spain during the period 1983 to 2013. The statistical significance of SPEI and SPI is shown for different timescales (1, 3, 6 and 9 months) in Poisson models ($p < 0.05$) for the period 1983 to 2013. Green crosses denote the position of the province capital.

the association with drought periods measured by SPEI and SPI was statistically significant for all accumulated months of study. In A Coruña, this effect was observed only when the droughts were measured for the long term (SPEI-9 and SPI-9). Finally, according to the impact of drought periods on daily respiratory-cause mortality, in Lugo this effect was exhibited with SPEI-1 and SPI-1, while in Ourense the relationship was statistically significant using both SPEI and SPI for the short term (1 month), medium term (3 months), and long term (9 months).

Fig. 4 represents the RRs as a function of the best indicator (SPEI-n and SPI-n), with a confidence level of 95% ($p < 0.05$) in the provincial capital cities of Galicia during the studied period of 1983 to 2013. According to it, in **Ourense**, there was greater statistical significance for the effect of drought for SPEI-1 and SPI-1 on daily natural- and respiratory-cause mortality. For SPEI-1, RR was 1.057 (95% CI: 1.020–1.095) for respiratory-cause mortality and 1.018 (95% CI: 1.006–1.030) for natural causes. For SPI-1, RR was 1.017 (95% CI: 1.005–1.028) for natural-cause mortality and 1.060 (95% CI: 1025–1096) for respiratory causes. In **Lugo**, daily respiratory-cause mortality attributable to drought was also more significant for the first month of accumulation, using both series of drought indicators (RR = 1.046 (95% CI: 1.007–1.087) for SPEI-1 and RR = 1.042 (95% CI: 1.005–1.080) for SPI-1). At the 3-month accumulation, RR = 1.023 (95% CI: 1.010, 1.037) for natural causes using both drought indices, and for circulatory-cause mortality RR was 1.049 (95% CI: 1.027, 1.071) using SPEI-3, and 1.045 (95% CI: 1.023, 1.066) using SPI-3. In the case of **A Coruña**, only daily circulatory-cause mortality associated with droughts was manifested when droughts were measured for the long-term, using both indicators as RR was 1.017 (95% CI: 1.004, 1.030) using SPEI-9 and 1.015 (95% CI: 1.003, 1.028) using SPI-9.

Fig. 5 shows the representation for the four provincial capital cities of Galicia of the percentage of attributable risk (%AR) that was only obtained from the RR value for those indices with the greatest statistical significance across 1983 to 2013. The increase in respiratory and circulatory causes of daily mortality attributable to drought periods compared to daily natural-cause mortality was notable. In Ourense, the increase in daily respiratory-cause mortality associated with drought periods were 5.4% and 5.7% when droughts were measured with SPEI1 and SPI1, respectively. Also remarkable is the %AR of respiratory and circulatory causes of daily mortality associated with droughts in Lugo (% AR: 4.4 using SPEI-1 and 4.0 using SPI-1 in relation with the daily respiratory-cause mortality and 4.7 using SPEI-3 and 4.3 using SPI-3 with respect to the daily cardiovascular-cause mortality). On the other hand, the value of %AR obtained in terms of daily natural-cause mortality associated with droughts was 2.3% in Lugo using both SPEI-3 and SPI-3, and 1.8% and 1.7% in Ourense using SPEI-1 and SPI-1, respectively. In addition, the increase in daily circulatory-cause mortality attributable to drought periods in A Coruña was 1.7% using SPEI-9 and 1.5% using SPI-9.

Additionally, we have checked the significance for the categorized SPEI-n and SPI-n series for the relations founded with the continuous ones. We have considered two categories of severity: moderate and high (comprising the severe and extreme groups jointly due that the extreme events only represent between 0.89% to 6.69%, and between 2.48% to 17.01% of days with drought using SPEI and SPI, respectively). According to this, in the interior regions of Galicia the mainly the effect on mortality is due to high severity drought events, while in the coastal area of A Coruña is mainly manifested for moderate severity at long time scale (see Table S3 of supplementary material).

3.2.2. Daily mortality causes under drought conditions merged with the effect of heat waves and pollution during 2000–2009

In this study, we have also studied the effect of droughts measured at short-term (1 month) across 2000 to 2009 to include in the analysis the evaluation of the effect of heat waves and pollution (mean O_3, NO_2, and PM_{10} concentrations). As the period with pollution data is shorter, we repeat the previous analysis for this "new" sub-period and only for SPEI-1 and SPI-1. According to our results (Table 1) only in interior regions of Galicia (Ourense and Lugo) there are statistically significant associations between different causes of daily mortality and drought conditions. In addition, the use of SPEI-1 or SPI-1 reveals are equivalent results. In both provinces all daily causes of mortality were significant associated with drought at short time, but with greater impact in daily respiratory-cause mortality. For Ourense, unlike for 1983–2013 results, it was observed a significant relationship with daily-circulatory cause mortality.

When we controlled drought indicators and heatwaves in Poisson models it has observed statistically significant results for both climatic variables in Lugo and Ourense at short-term, with the exception for Ourense in daily respiratory-cause mortality (only observed for SPEI-1 and

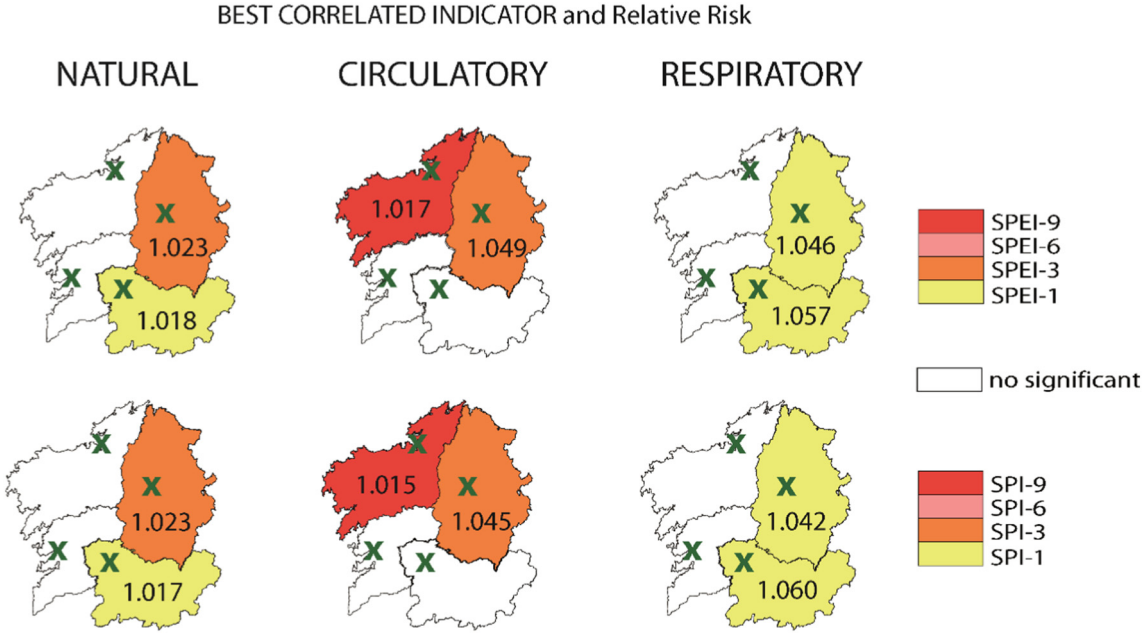

Fig. 4. Summary of the representation of relative risk (RR) of natural, circulatory, and respiratory causes of daily mortality attributable to drought periods in northwest Spain in the period 1983 to 2013. The relative risk of SPEI and SPI obtained by the most statistically significant timescale from the Poisson model ($p < 0.05$) throughout the period 1983 to 2013. Green crosses denote the position of the capital of each province.

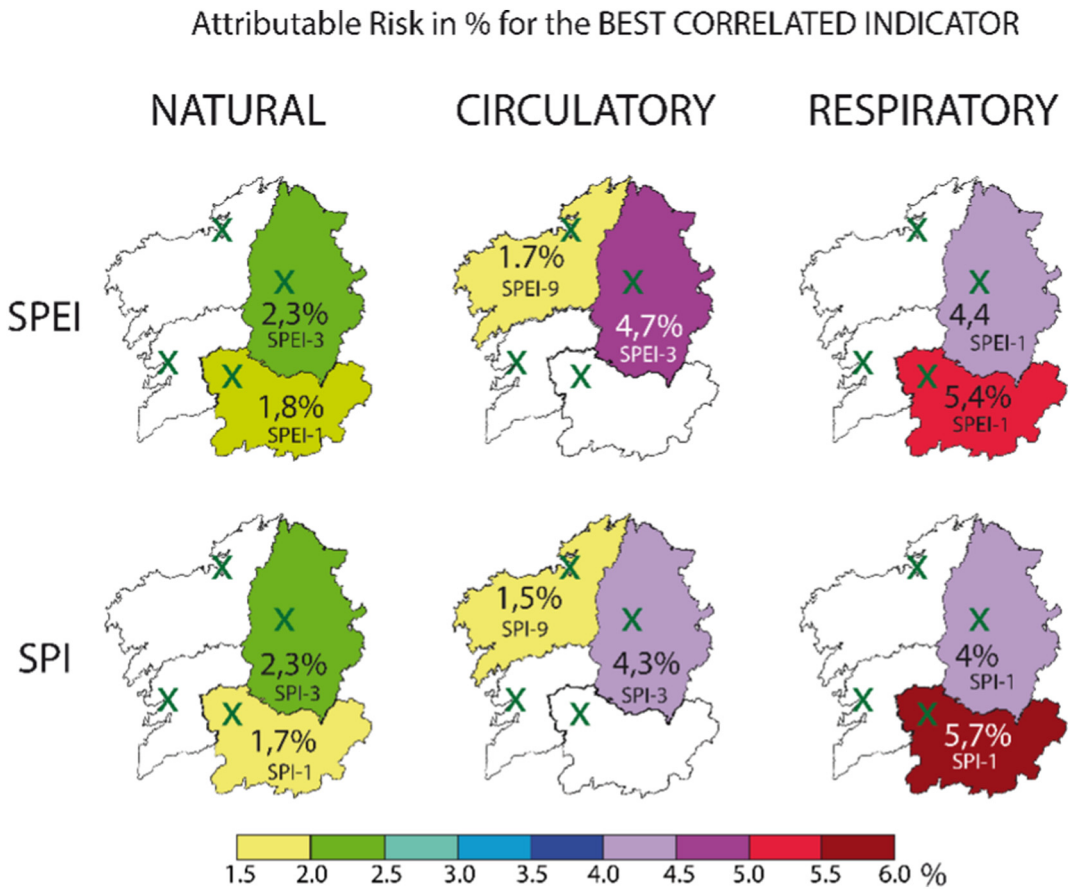

Fig. 5. Summary of the percentage of attributable risk (%AR) associated with natural, circulatory, and respiratory causes of daily mortality associated with droughts in northwest Spain, Galicia, during the period 1983 to 2013. The %AR in each province is shown where there was a relation between the different causes of mortality and drought conditions measured by the most statistically significant timescale between SPEI and SPI in the Poisson model ($p < 0.05$). Green crosses denote the position of the capital of each province.

SPI-1). In addition, the effect of drought on circulatory-cause mortality in Lugo only resulted significant for SPEI-1.

Furthermore, the effect of the heatwaves on daily mortality associated with drought events mainly occur up to one-day delay, except for Lugo with daily circulatory-cause mortality that was delayed up to four days, (Table 2).

On the other hand, besides to controlling drought and extreme temperatures, we controlled atmospheric pollution (daily mean O_3, NO_2 and PM_{10} concentrations levels) jointly in Ourense (Table 3) - due to there was no available pollutants data for Lugo -. According to the results, only NO_2 and PM_{10} were the variables statistically associated with daily natural and circulatory- causes mortality and only PM_{10} with respiratory-cause mortality, while drought indicators and heatwaves were no longer statistically significant. In any way, the strongest relation was observed between pollutants and daily respiratory-cause mortality.

Table 1
Summary of the statistically significant results obtained from Poisson modelling during 2000 to 2009 period. The table illustrates the statistically significant SPEI-1 and SPI-1 drought indicators ($p < 0.05$) that influence daily natural, circulatory, and respiratory-cause mortality for Ourense and Lugo in the period 2000–2009. The relative risk (RR) was calculated from the value of the estimator obtained in each model. The 95% confidence intervals of the estimator is displayed. Decreasing SPEI and SPI values of coefficient indicates worsening drought. Conf. Interval = Confidence Interval.

Ourense	p-Value	Coefficient	Coefficient [95% conf. interval]	Relative risk (RR)	RR [95% conf. interval]
Natural deaths	SPEI-1 p = 0.000	−0.04	(−0.064, −0.025)	1.046	(1.025, 1.066)
	SPI-1 p = 0.000	−0.045	(−0.064, −0.026)	1.046	(1.025, 1.066)
Circulatory deaths	SPEI-1 p = 0.000	−0.066	(−0.099, −0.034)	1.068	(1.035, 1.104)
	SPI-1 p = 0.000	−0.064	(−0.095, −0.032)	1.066	(1.032, 1.100)
Respiratory deaths	SPEI1 p = 0.001	−0.094	(−0.148, −0.040)	1.099	(1.041, 1.160)
	SPI1 p = 0.000	−0.094	(−0.146, −0.043)	1.099	(1.044, 1.157)
Lugo	p-Value	Coefficient	Coefficient [95% conf. interval]	Relative risk (RR)	RR [95% conf. interval]
Natural deaths	SPEI-1 p = 0.000	−0.043	(−0.066, −0.021)	1.044	(1.021, 1.068)
	SPI-1 p = 0.001	−0.038	(−0.060, −0.015)	1.039	(1.015, 1.062)
Circulatory deaths	SPEI-1 p = 0.003	−0.060	(−0.099, −0.021)	1.062	(1.021, 1.104)
	SPI-1 p = 0.017	−0.046	(−0.084, −0.008)	1.047	(1.008, 1.088)
Respiratory deaths	SPEI1 p = 0.001	−0.109	(−0.173, −0.045)	1.115	(1.046, 1.189)
	SPI1 p = 0.002	−0.097	(−0.157, −0.036)	1.102	(1.037, 1.170)

Table 2
Summary of the statistical significance results obtained from Poisson modelling taking into account the impact of the heatwaves during drought periods measured by SPEI-1 and SPI-1 during 2000 to 2009. The table shows the statistically significant results in Ourense (top) and in Lugo (bottom) using indicators of drought at short-term and daily extreme temperatures in Poisson models. The relative risk (RR) was calculated from the value of the estimator obtained in each model. The 95% confidence intervals of the estimator and of the RR are displayed. Conf. Interval = Confidence Interval.

Ourense	Indicator	Drought indicator + extreme temperatures (Thwave)					
		p-Value	Lag in days	Coefficient	Coefficient [95% conf. interval]	Relative risk (RR)	RR [95% conf. interval]
Natural deaths	SPEI-1	SPEI-1 p = 0.000		−0.043	(−0.063, −0.024)	1.013	(1.024, 1.065)
		Thwave p = 0.000	1	0.107	(0.061,0.153)	1.113	(1.063, 1.165)
	SPI-1	SPI-1 p = 0.000		−0.045	(−0.064, −0.026)	1.046	(1.026, 1.066)
		Thwave p = 0.000	1	0.110	(0.064, 0.155)	1.116	(1.066, 1.168)
Circulatory deaths	SPEI-1	SPEI-1 p = 0.000		−0.064	(−0.097, −0.031)	1.066	(1.031, 1.102)
		Thwave p = 0.000	1	0.149	(0.077, 0.221)	1.161	(1.080, 1.247)
	SPI-1	SPI-1 p = 0.000		−0.063	(−0.094, −0.031)	1.066	(1.031, 1.099)
		Thwave p = 0.000	1	0.153	(0.081, 0.225)	1.165	(1.084, 1.252)
Respiratory deaths	SPEI-1	SPEI1 p = 0.001		−0.094	(−0.148, −0.040)	1.099	(1.041, 1.160)
	SPI-1	SPI1 p = 0.000		−0.094	(−0.146, −0.043)	1.099	(1.044, 1.157)
Lugo	Indicator	Drought indicator + extreme temperatures (Thwave)					
		p-Value	Lag in days	Coefficient	Coefficient [95% conf. interval]	Relative risk (RR)	RR [95% conf. interval]
Natural deaths	SPEI-1	SPEI-1 p = 0.002		−0.038	(−0.062, −0.015)	1.039	(1.015, 1.064)
		Thwave p = 0.003	1	0.140	(0.048, 0.231)	1.150	(1.049, 1.260)
	SPI-1	SPI-1 p = 0.003		−0.036	(−0.060, −0.012)	1.037	(1.012, 1.062)
		Thwave p = 0.002	1	0.142	(0.051, 0.234)	1.153	(1.052, 1.264)
Circulatory deaths	SPEI-1	SPEI-1 p = 0.018		−0.049	(−0.090, −0.009)	1.050	(1.009, 1.094)
		Thwave p = 0.000	4	0.269	(0.141, 0.398)	1.309	(1.151, 1.489)
	SPI-1	Thwave p = 0.000	4	0.275	(0.146, 0.403)	1.309	(1.157, 1.496)
Respiratory deaths	SPEI-1	SPEI1 p = 0.003		−0.104	(−0.173, −0.036)	1.110	(1.037, 1.189)
		Thwave1 p = 0.027	1	0.263	(0.029, 0.496)	1.301	(1.029, 1.642)
	SPI-1	SPI1 p = 0.002		−0.106	(−0.174, −0.038)	1.112	(1.039, 1.190)
		Thwave p = 0.020	1	0.277	(0.043, 0.511)	1.319	(1.044, 1.667)

Mainly, the pollutants effect on natural and circulatory causes it has observed up to one day of delay, reaching 5 days for NO_2 on circulatory causes, and the effect is during the same day (lag = 0) for PM_{10} in respiratory causes of mortality (Table 3).

4. Discussion

This paper evaluates for the first time the effect of the droughts measured by SPEI and SPI on daily natural and specific (circulatory and respiratory) causes of mortality for each province of Galicia throughout the 1983 to 2013 period. In addition, droughts were measured for different timescales (1, 3, 6, and 9 months) to evaluate the periods of accumulation in which the different causes of daily mortality were manifested, comparing the results obtained by both indicators. Based on the results of this study and considering the values of the coefficients obtained using a GLM, the negative sign indicates an inverse relationship between both variables, so that the more intense the hydrological extreme, the greater its impact on daily mortality.

A greater impact on daily mortality has been observed in the interior provinces of Galicia than in the coastal areas. Specifically, Lugo, the region with the greatest number of days with drought and with the highest value of accumulating days with severe and extreme drought, was the most affected province in terms of health. There were statistically significant associations between the drought, using both SPEI and SPI, and the daily natural- and circulatory-cause mortality in the short, medium, and long term, while the association with daily respiratory-cause mortality appears only in short term. In Pontevedra, the region with the lowest number of days with drought and with the lowest value of accumulating days with severe and extreme drought, there was no a relationship observed between any studied variables (see Table S2 and Fig. 3). According to the best statistically significant timescales, in the interior regions of Galicia, the daily mortality associated with drought is mainly manifested for shorter periods of accumulation but with much higher impact than in the coastal regions. However, in A Coruña, it is necessary that the drought occurs for a long time (9 months) to observe a significant association with daily circulatory-cause mortality, obtaining less impact than the interior regions,

Table 3
Summary of the statistical significance results obtained from Poisson modelling taking into account the impact of the daily pollutant concentration during drought periods in Ourense measured by SPEI-1 and SPI-1 during 2000 to 2009. The table shows the statistically significant results in Ourense using indicators of drought at short-term, daily pollution variables (O_3, NO_2 and PM_{10} concentrations) and extreme temperatures in Poisson models. Data for Lugo is not available. The relative risk (RR) was calculated from the value of the estimator obtained in each model. The 95% confidence intervals of the estimator and of the RR are displayed. Conf. Interval = Confidence Interval.

Ourense	Indicator	Drought indicator + extreme temperatures (Thwave) + pollution (mean O_3, NO_2, PM_{10} concentrations)					
		p-Value	Lag in days	Coefficient	Coefficient [95% conf. interval]	Relative risk (RR)	RR [95% conf. interval]
Natural deaths	SPEI1	NO_2 (p = 0.001)	1	0.005	(0.002, 0.008)	1.005	(1.002, 1.008)
		PM_{10} (p = 0.000)	1	0.006	(0.003, 0.009)	1.006	(1.003, 1.009)
	SPI1	NO_2 (p = 0.001)	1	0.005	(0.002, 0.008)	1.005	(1.002, 1.008)
		PM_{10} (p = 0.000)	1	0.006	(0.003, 0.009)	1.006	(1.003, 1.009)
Circulatory deaths	SPEI1	NO_2 (p = 0.007)	5	0.006	(0.002, 0.011)	1.006	(1.002, 1.011)
		PM_{10} (p = 0.012)	1	0.007	(0.001, 0.012)	1.007	(1.001, 1.012)
	SPI1	NO_2 (p = 0.007)	5	0.006	(0.002, 0.011)	1.006	(1.002, 1.011)
		PM_{10} (p = 0.012)	1	0.007	(0.001, 0.012)	1.007	(1.001, 1.012)
Respiratory deaths	SPEI1	PM_{10} (p = 0.000)	0	0.014	(0.007, 0.021)	1.014	(1.007, 1.021)
	SPI1	PM_{10} (p = 0.000)	0	0.014	(0.007, 0.021)	1.014	(1.007, 1.021)

probably due to the presence of heavier droughts in the interior than in the coastal regions (see Figs. 4–5).

The variability of these findings could also be explained by other variables that could influence the impact of hydrological extremes on health (IPCC, 2014; Stanke et al., 2013; Ebi and Bowen, 2016). Although variables such as trend, seasonality, and the autoregressive nature of the series were controlled, we were unable to examine the individual socioeconomic status, the previous vulnerability, and health of the population or socioeconomic status and race, showing a limitation of this type of studies. In addition, differences in pollution levels and humidity between different regions could aggravate the effects of drought in interior areas compared to coastal regions.

There are evidences that associate drought conditions with an increased risk of morbidity and mortality (Hanigan et al., 2012; Stanke et al., 2013; Yusa et al., 2015; Berman et al., 2017). However, more conclusive studies are needed, specifically on respiratory- and circulatory-cause mortality. According to our results, daily respiratory- and circulatory-causes of mortality were the most related to drought periods conditions, with the higher RR and % RA (Figs. 4–5). Concretely, daily respiratory-cause mortality in Ourense was the study group most affected by droughts in the short-term (Fig. 5).

In this context, although the biological mechanisms through which droughts affect disease and death are not well-known, indirect effects of drought events have been described in respiratory and circulatory health, and in mortality (Berman et al., 2017). It is remarkable that drought is an indirect indicator that incorporates and reflects the effects of different environmental factors, which have been considered individually in several works, such as heatwaves, forest fires, and pollution, with great importance in mortality, especially in vulnerable populations. High temperatures are associated with the intensification of droughts (Bandyopadhyay et al., 2016; Sapionini et al., 2017), and both phenomena are related to drier soils, deforestation, increase the incidence and intensity of wildfires, dust storms as well as conditions that lead to increase in the reduction in air quality (Smoyer-Tomic et al., 2004; Westerling et al., 2006; IPCC, 2014; Patz et al., 2014; Smith et al., 2014; Yusa et al., 2015; Ebi and Bowen, 2016, Bell et al., 2018). All these events associated with droughts lead to an increase in dust, which can transport pathogens or PM, and a rise in the release of toxic aerosols in the atmosphere with potential effects in health (Smoyer-Tomic et al., 2004; Johnston et al., 2011; Finlay et al., 2012; Smith et al., 2014; Linares et al., 2017; Bell et al., 2018). In this point, it should be noted that although SPEI incorporates temperature data is difficult to use this type of indicator to disentangle the direct health effects of temperature from increased evapotranspiration and in the rise in drought severity that can imply.

For all these reasons, in the second part of this study we have analysed the effect of extreme temperatures (heatwaves) and mean O_3, NO_2 and PM_{10} concentrations associated to droughts on daily mortality in the short-term during 2000 to 2009. Only for interior provinces of Galicia there were statistically significant associations (Table 1).

When only droughts and heatwaves were considered it has observed that in the short-term, the effect on daily mortality was due to a synergic effect of both in Ourense and Lugo (with the exception to respiratory-cause mortality in Ourense that was only due to the effect of droughts) (Table 2). However, when pollutant were added as third climatic factor, in Ourense there was only a significant relationship between atmospheric pollution and the different causes of daily mortality in the short-term. In this case, the statistically association between drought, heatwave and daily mortality variables no longer observed when pollution was considered (Table 3). Thus, these findings suggest that in the short-term, the observable effect of droughts measured by SPEI-1 and SPI-1 and heatwaves on daily mortality across 2000 to 2009 was explained by the atmospheric pollution effect (higher PM and NO_2 concentrations).

Heatwaves and extremely high temperatures have been associated with natural, circulatory and respiratory causes of mortality in Spain in several longitudinal studies (Tobías et al., 2014; Linares et al., 2015b; Carmona et al., 2016; Linares et al., 2017). In Galicia as a whole, maximum temperature increase of 1 °C was more strongly associated with respiratory-cause mortality (RR: 1.14) than circulatory-cause mortality (RR: 1.06) (Diaz et al., 2015; Linares et al., 2017, and in addition, people over 65 years old were markedly more affected (Díaz et al., 2002; Linares and Diaz, 2008). These effects attributable to high temperatures will be conditioned by the physiological state and vulnerability of the individual (Linares et al., 2017). On the other hand, Díaz et al. (2012) showed that in Madrid (interior region of Spain) levels of PMs from anthropogenic origin can be strongly increase in days with Sahara dust intrusions, which occur more frequent in warmer months, when heatwaves usually take place. This fact can led to harmful effects on circulatory and respiratory health.

With respect to **high pollution levels**, Berman et al. (2017), in their study over USA for 2000–2013, indicated that drought periods were associated with an increase in daily concentrations of dust (PM with aerodynamic diameter of >2.5 μm and less than or equal to 10 μm or PM course), although also in decrease in $PM_{2.5}$. Several multicentre studies in the USA, Canada, and Europe strongly associated effects of short-term PM_{10} exposure with circulatory and respiratory causes of mortality (U.S. EPA, 2009).

In accordance with our findings, droughts in the short-term could be explaining under situations with maintained anticyclones. In the study by Ficher et al. (2007) about the heatwave occurred during summer 2003 the drought conditions probably amplified and lengthened the anticyclonic events. The anticyclones generate blocking situations, favoring the increase in pollutants such as PM_{10} and NO_2 associated with the stagnant conditions (Thishan Dharshana et al., 2010; AIRPARIF, 2016). The high mean concentrations of NO_2 suggest that probably the pollution was mainly of anthropogenic origin as it is a primary pollutant due to road traffic (Linares et al., 2018a).

PM can pass through the respiratory tract where is deposited exacerbating chronic respiratory and circulatory diseases due to local and systemic inflammation and the establishment of oxidative and nitrosative stress, as well as cellular toxicity due to PM inhalation. This results in cell damage and injury (Linares et al., 2018b; Jalava et al., 2006; Xia et al., 2007; U.S. EPA, 2009; Haikerwal et al., 2015; Ortiz et al., 2017). In the circulatory system, these events have been related to prothrombotic effects, endothelial dysfunction and acceleration of atherosclerotic processes, with consequent vessel obstruction and a decrease in blood flow. In addition, this can lead to atherosclerotic plaque rupture, myocardial infarction, and stroke (Pope 3rd et al., 2004; U.S. EPA, 2009; Haikerwal et al., 2015; Reid et al., 2016; Ortiz et al., 2017). PM has also been related to vessel reactivity affectation (U.S. EPA, 2009) and alteration of cardiac autonomic function, which can increase the risk of dysrhythmia, heart failure, and cardiac arrest (Pope 3rd et al., 2004).

A study on the evaluation of short-term mortality attributable to PM pollution in Spain (Ortiz et al., 2017) indicated a higher RR (1.026) for respiratory-cause mortality corresponding to increase of 10 $\mu g/m^3$ in PM_{10} concentrations than for natural- and circulatory-cause mortality (RR = 1.009 for both causes). In the case of NO_2 concentrations (Linares et al., 2018a) it was found a similar order for the RR of daily causes of mortality (RR = 1.028, RR = 1.016, and RR = 1.012, respectively for respiratory, circulatory, and natural mortality).

Although in this study we have not evaluated a direct relationship between droughts and wildfires, it should take into account that they are event strongly associated and can probably play an important role in specific causes of mortality in the short-term. Specifically, a study estimated that 339,000 premature deaths per year worldwide are attributable to pollution derived from forest fires, especially due to PM, which is the most prevalent air pollutant in the smoke of wildfires after the burning of biomass (Johnston et al., 2012). Linares et al. (2018b) showed the association between daily mortality and the increase in PM concentrations produced by biomass combustion from

wildfires in Spain in regions where they were more frequent, including the northwest, throughout the 2004 to 2009 period (Linares et al., 2015a). In addition, daily-respiratory cause mortality is mainly the cause most related to this climatic extreme. Interior provinces of Galicia (Ourense and Lugo), which we had proved the most affected by drought events, are the most affected regions with the highest number of forest fires and the largest areas burned. In particular, during 2017, Ourense accounted for about 50% (30,000 ha) of the total burned area in Galicia (62,000 ha) (Mapama, 2017). However, it should be necessary conducted conclusive studies that analysing the association between droughts and wildfires.

The manifestation of daily mortality effects for prolonged timescales may be associated with mental health, especially in rural populations. Although we could not measure levels of stress in this retrospective study, there are several studies that have documented the association between droughts and psychological stress, psychological distress, generalized anxiety, and depression, that in extreme cases, could even be a contributing factor to mortality by suicide (Berry et al., 2010; Hanigan et al., 2012; Shukla, 2013; IPCC, 2014; OBrien et al., 2014; Sena et al., 2014; Yusa et al., 2015; Vins et al., 2015; Berman et al., 2017).

Chronic stress causes prolonged and persistent overactivation of the hypothalamic pituitary adrenal axis and the medullary adrenal sympathetic axis, which ultimately has direct effects on physiological processes and patterns of behaviour (Cohen et al., 2007; Vida et al., 2014). Murine models have shown that chronic stress and anxiety are related to the establishment of oxidative and inflammatory stress, which leads to the deterioration of the regulatory systems: nervous, immune, and endocrine, as well as the neuroimmunoendocrine communication. Ultimately, these events can lead to premature immunosenescence, decrease in homeostasis, dysfunction of an organism's systems, and therefore, a loss of good health and premature mortality (Vida et al., 2014). In particular, stress can be an important factor in respiratory tract infections and can promote cardiac pathogenic processes, such as myocardial ischemia and activation of inflammatory and coagulation mechanisms (Von Känel et al., 2001; Cohen et al., 2007). In any case, more exhaustive studies should be done to better understand the link of stress as a causal effector.

In addition, in this work is the first time that a comparison between the effects of periods of drought measured by the SPEI and SPI indices on daily mortality in a particular region of Europe was conducted, Galicia. The findings indicate that statistically significant differences between both types of indices hardly exist from the periods of study nor with respect to the timescales of both indicators (SPEI-n vs SPI-n). Thus, the indistinct use of either index could be valid to evaluate the risk of drought in terms of health in Galicia, probably due to precipitation is likely the most important variable when considering drought measurement. This is in concordance with a previous work by Vicente-Serrano et al. (2011) that analysed the evolution of drought severity on the NW Iberian Peninsula from 1930 to 2006 and no significant differences were found when it was measured by SPEI and SPI. However, according to warming projections of climate change (Patz et al., 2005; Carmona et al., 2016), SPEI could provide a better estimate of the severity of drought, as result of water by evapotranspiration (Beguería et al., 2014), and a better adjustment of the risk in health in the near future. Specifically in Spain an increase of between 3 and 5 °C and even 5–7 °C in the warmest months has been predicted to occur by the end of the 21st century (Morata-Gasca, 2014).

Finally, it should be noted that the findings obtained in this study include only the NW region of Spain, which implies a restriction in obtaining broader conclusions at the population level in Spain as a whole, showing a limitation of this study.

5. Conclusion

The main findings of this study are that daily mortality in the interior regions of Galicia are more affected by drought than in the coastal regions. In the interior provinces of Galicia, the effects on daily mortality suggest that they are associated with droughts mainly measured for shorter timescales. In the coastal province of A Coruña, the daily mortality is manifested with longer droughts. Moreover, there are hardly differences between SPEI and SPI, so both indicators are valid to assess the effects of droughts in terms of health. On the other hand, the results suggest that in short-term, the synergic effect of droughts measured by SPEI-1/SPI-1 and heatwaves on daily mortality observed in interior regions is mainly explained by atmospheric pollution effect in Ourense, during the 2000–2009 period. In addition, daily respiratory-cause mortality is the cause most associated to this extreme climatic event throughout all study. Taking into account the fact that many people are exposed to these extreme climatic events at a regional level, considering the future projections of climate change as well as the limited information on this issue in the scientific literature, these studies are crucial to public health, so that these serious effects attributable to drought periods can be minimized. The dichotomy seen in this study in reference to the behaviour of mortality and droughts between coastal and inland regions, as well as the different effects due to droughts in the short, medium or long term, will serve as an important point of departure in analysing the effect of droughts for different timescales for major regions such as the Iberian Peninsula.

Disclaimer

This paper reports independent results and research. The views expressed are those of the authors and not necessarily those of the Carlos III Institute of Health.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2019.01.217.

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